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THE DEVELOPMENT OF AËRIAL NAVIGATION.

BY HIRAM S. MAXIM.

In 1890 I tried a series of experiments with a view of ascertaining how much power was required to perform artificial flight. An account of these experiments written by myself, and entitled "Aërial Navigation—The Power Required," appeared in the *Century* Magazine of October, 1891. The apparatus used in these experiments was constructed with great care and was provided with all sorts of delicate instruments which enabled me to ascertain definitely the exact power required for performing artificial flight on the aëroplane system driven by screw propellers.

As is well known, when one flies a kite the cord holds the kite against the wind. The wind passing on the under side of the kite strikes it at an angle and raises the kite into the air. If the wind be blowing at a high velocity—say 35 miles an hour—the kite will lift from one pound to five pounds per square foot, according to the angle at which it is held in the air. If the angle be slight, the amount of strain on the cord necessary to hold it against the wind will be found considerably less than the weight of the kite and the load which it is able to lift, particularly so if the cord pulls in a horizontal direction instead of at an angle. It is also well known that if a kite be propelled in a calm through the air, say at the rate of 35 miles an hour, the effect is exactly the same. Suppose now, instead of the cord for holding the kite against the wind or for propelling it against still air, that a screw propeller should be attached to the kite and that it should be driven by some motor. If the screw propeller could be made to give a push equal to the pull of the kite, and if the machinery for driving it should be no greater than the weight that the kite would be able to carry, we should have a veritable flying machine.

In my first experiments to ascertain the power required, the aëroplanes employed were formed of thin pieces of wood, the under side being slightly concave and the top side slightly convex. These aëroplanes I was able to propel round a circle 200 feet in circumference at a speed say from 20 to 90 miles an hour, and with the planes at any desired angles. When the inclination was 1 in 14 it was found that a thrust of 5 pounds on the screw would lift 14 times 5 pounds, or 70 pounds, on the plane. It was also found in these experiments with a plane set at an angle of 1 in 14, that as much as 133 pounds could be carried with the expenditure of 1 horse power. These experiments, which were very full and complete, and which embraced many different kinds of screw propellers and aëroplanes, demonstrated that a two-bladed wooden propeller with a pitch slightly greater than the diameter, was the most advantageous, the propelling power being very great and the loss by slip comparatively small. Narrow aëroplanes slightly concave on the under side, set at a slight angle and driven at a high speed, were found to be the most efficient, and any distortion or bagging of the aëroplane increased enormously the power required.

Having ascertained experimentally the power required, I at once commenced experiments with a view of developing the necessary motive power. Everything considered, I believed that steam power would be more efficient for the weight than any other source of energy. First I made two pairs of compound engines, the high-pressure cylinders being 5 inches in diameter, the low-pressure cylinders 8 inches in diameter, and all having a stroke of 12 inches. In order to make the engines as light as possible, the cylinders were made about $\frac{3}{32}$ inch thick, of a high grade of fluid compressed steel. The valve chambers and passageways were made of seamless steel tubes, the whole being neatly riveted together and brazed with silver-solder.

The crank shaft was of comparatively large diameter, but hollow, and of highly tempered steel. All the piston and valve rods, and also the framework of the engine, were constructed of hard and thin tubular steel. When the engines were finished they were found to weigh 300 lbs. the pair, or 600 lbs. in all. The high-pressure cylinder was made with a considerable amount of clearance, so as to avoid danger if water should go over with the steam, and the piston valves were made to cut off at $\frac{3}{4}$ stroke, while steam was cut off in the low-pressure cylinder at $\frac{5}{8}$ stroke. Believing that on some occasions I might require to put on a tremendous spurt, I placed a kind of an injector valve between the high-pressure steam directly from the boiler and the exhaust from the high-pressure cylinder. This injector was provided with a spring valve regulated in such a manner that in case the boiler pressure should rise above 300 pounds to the square inch, instead of blowing off steam at the safety-valve, the steam would open a passage directly into the low-pressure cylinder, and, as the passageway was annular and arranged to be more or less large in proportion to the steam passing, the steam in falling from a high to a comparatively low pressure was made to do a certain amount of work on the exhaust steam, thus increasing the pressure in the low-pressure cylinder without greatly increasing the back pressure in the high-pressure cylinder. This is a new feature, which, I think, has never been used on a compound engine before.

The first steam generator was constructed of a very large number of small and thin tubes. It was constructed so as to admit water at one end of the series and to draw steam from the other end, and to so regulate the fire as to convert about 90 per cent. of the passing water into steam. This boiler was of great lightness, not weighing without its casing more than 300 pounds, and was heated by 50 square feet of flame; but it was found impossible to so regulate the fire and the water supply as to have comparatively dry steam without destroying some of the tubes. If twice as much water as is evaporated was pumped through the boiler, it stood the heat fairly well; but upon any attempt being made to reduce the quantity of water, some of the small tubes, which were of copper, would invariably burst. This boiler was, however, remarkable because steam could be raised in about ten seconds, and on some occasions an ample supply of steam was made to run the engines up to 300 horse power.

The first boiler having failed, I at once determined to make a boiler on a new plan, but before doing so I tried a series of experiments so as to be sure of my ground in my second attempt. I obtained a quantity of copper tubes $\frac{3}{8}$ of an inch diameter, $\frac{1}{50}$ of an inch thick, and 8 feet long. Four of these were connected together and provided with a forced circulation; they were then placed in a white-hot furnace and made to evaporate at the rate of $26\frac{1}{2}$ pounds of water per square foot per hour at a pressure of 400 pounds to the square inch. Having stood this test, a single tube was placed in a white-hot furnace similarly connected, with a view of finding the bursting pressure under steam. It exploded 1,650 pounds to the square foot. Some hundreds of tubes were then tested with one ton per square inch pressure of cold kerosene oil, and as none of them showed any signs of leaking, the new boiler was constructed of these tubes. The general form was somewhat similar to the water-tube boilers employed on torpedo boats in France and England, except that the tubes were relatively much longer for their diameter and had twice as many bends in them, and to insure circulation a down-take for the water outside of the firebox was provided. The feed-water in coming from the pump passed through a very elaborate network of fine copper tubes immediately over the boiler and at a pressure 30 pounds greater than the boiler pressure. A spring valve nozzle was interposed between the feed-water heater and the down-take for the water in such a manner that the escaping force of the water operated powerfully on the surrounding water in the down-take, and thus secured a very rapid circulation through the long and slender tubes which formed the main heating surface of the boiler. This new boiler has proved itself to be very efficient indeed ; the network of very fine tubes which forms the feed-water heater greatly reduces the temperature of the escaping products of combustion, so that the heating of the top of the casing of the boiler is never great enough to burn paint off the smokestack. The new boiler was first tested to 410 pounds cold water pressure, and then to 325 pounds steam pressure. Having completed the new boiler it was placed in position, and experiments commenced with petroleum burners. The new boiler had a very much reduced firebox. Whereas the first experimental boiler had what might be called 40 square feet of grate surface, the new boiler had only 28 square feet. In ordinary boilers heated by petroleum the furnace is supplied with one or two very powerful jets, burning against brickwork or fireclay. This, of course, would be quite out of the question with a flying-machine boiler. Moreover, with such a light boiler it was not advisable to have a very intense flame; what was necessary, of course, was a very large and even flame, so as to heat all tubes equally. The first burners experimented with worked all right for about 100 horse power ; but whenever any attempt was made to increase the flame, great unevenness in the flame occurred, some parts of the firebox being filled with flame, while other parts had no flame at all. After much experimenting I finally decided to use naphtha, 72 degrees Beaumé.

The naphtha was pumped into a small and exceedingly light vertical boiler, where it was heated with a flame generated from part of its own contents arranged in such a manner that whenever the pressure of the gas or the vapors of petroleum exceeded 50 pounds to the square inch the flame was automatically shut off, while if the pressure fell slightly below this the flame was turned on so that, no matter how much gas or vapor was drawn from the boiler, the pressure remained constant. This small boiler was suspended by springs in such a manner that whenever the weight of the contents exceeded 40 pounds, it moved the boiler slightly downwards, which operated upon an escapement on the pumping mechanism in such a manner that when the weight was greater than 40 pounds the stroke of the pump was diminished; while if the weight was less than 40 pounds the stroke was increased. This apparatus was found to work admirably ; and no matter how much or how little gas was drawn from the generator, the weight of liquid and pressure of gas always remained constant. The vapor was led from the generator through a pipe in the furnace, where it became superheated, and then was blown through a species of an injector into the furnace, sucking a large quantity of air through a suitable opening, which could be regulated so as to make the gas of any desired density.

Many burners were experimented with, the first one having as many as 14,000 jets ; the one finally adopted had 7,650 burners, and was so arranged that any amount of gas might be consumed without any unevenness, smoking, or blowing. Having perfected my boiler, my gas generator, and my pumping apparatus, so that all worked smoothly and automatically, I attached a pair of very large and carefully made linen-covered wooden screws to the screw shafts. These screws were 17 feet 10 inches in diameter, and had a slightly increasing pitch, the mean pitch being rather more than 16 feet. It will be understood that the boiler was placed upon a platform about 8 feet wide and 40 feet long ; that the engines and screws were held by strong tubular brackets above the rear end of this platform, and that the whole was mounted on four steel wheels; that there were springs interposed between the axletrees of these wheels and the platform; and also that there were vertical tubes and wires attached to the platform which held the large aëroplane, which is about thirty feet by fifty feet, in position.

At the same time that the experiments were going on with the burners and boilers, a railway track 1,800 feet long was being laid, and the framework of the machine was being brought to a state of completion. Upon moving the machine on to the track, tying it up and attaching it to a dynamometer, I filled the boiler with water, got up steam with a slow fire in about three minutes and started my engines, when everything was found to run very smoothly indeed.

With 200 pounds pressure to the square inch, the thrust of the screws was about 1,400 pounds, but by running the pressure up to 325 pounds to the square inch, the thrust of the screws went up in the first instance to 1,160 pounds, and finally in a later trial to 1,260 pounds. These experiments should have been tried on a railway track of considerable length, but as I was only able to get a clear track of 1,800 feet, it was found necessary to provide suitable mechanism in order to bring the machine to a state of rest without injury. The best apparatus for this purpose was found to be a series of very strong ropes stretched across the track, each end of the rope being attached to a capstan, and each capstan being provided with a strong plank which acted as a fan. This apparatus stopped the machine without the least shock.

The first experiments were tried without any cloth on the framework and it was found that when the machine was liberated it started off very quickly, in fact so quickly that it nearly threw down any one who was standing upon it.

After having tried several experiments with the naked framework, the main aëroplane was put in position and a few runs made, but the bagging and distortion of the cloth was such that it required the full power of the engines with a screw-thrust of 2,000 pounds to drive the machine at the rate of 25 miles an hour, and the lift did not exceed the thrust of the screws. This aëroplane was then removed and a new one substituted. The second aëroplane was made of two thicknesses of cloth completely inclosing the framework and arranged in such a manner that a portion of the air could pass through the lower side and produce a slight pressure of air between the two thicknesses. The top side would therefore bag upwards and take the lift, while the bottom side having practically the same pressure on both sides would remain perfectly straight and would not be distorted in the least by running.

The first experiments with this new aëroplane were tried with a screw-thrust of about eight hundred pounds, and the lifting power was actually more than with the old aëroplane with two thousand pounds thrust. Upon increasing the screw-thrust to one thousand two hundred pounds, the lift of the aëroplane was greatly increased, so that the front wheels barely touched the track. I saw that it would not do to run at a greater speed, so I put on some very heavy wheels, weighing six hundred pounds each, which I believed would keep the machine on the track, even if I ran the engines at full speed. I then greatly increased the thrust of the screw, and, finally, ran over the track with a screw thrust of about fifteen hundred pounds ; but, unfortunately, I met a slight gust of wind coming from an opposite direction, which lifted the front end of the machine, wheels and all, completely off the track.

This accident, although it did not injure the machinery in the least, showed the weak points in the platform and framework of the machine, and I determined to rebuild it completely and to discard the heavy wheels. While the machine was being rebuilt I put up on each side of the railway track and about 10 feet from the rails a second track (inverted) of heavy wooden joists, and provided the new machine with four additional wheels placed at such a height that when the machine was raised one inch clear from the lower railway track, these new wheels on outriggers would engage the lower side of the joists and thus keep the machine from going off the track. This arrangement has been found to work exceedingly well. It is certainly a great improvement on the old heavy wheels, which not only made the starting and stopping of the machine more difficult, but also failed in keeping it on the track. The upper rail enabled me to make a large number of runs and to note carefully with suitable instruments exactly how much the machine lifted at various speeds. Having finished a series of experiments and ascertained the lift of the main aëroplane with a great degree of nicety, I placed the fore and aft rudders, which were intended to steer the machine in a vertical direction, in position, and made several runs with these rudders at different angles. They were found to work exceedingly well, and I was able to depress or elevate either end at will. The machine had been provided with ten auxiliary aëroplanes, which consisted of balloon cloth stretched very tightly on frames, and which could be placed one above the other (superposed) on each side of the machine if required. Of these ten aëroplanes only four were actually used, the lower ones which extend on either side of the machine 30 feet, and the upper ones which extend 27 feet each side of the main aëroplane and which bring up the total width of the machine to 104 feet. These long and comparatively narrow planes were found, as expected, to be more efficient foot for foot than the main aëroplane.

The first trials with these planes in position were made on the 31st of July last on a perfectly calm day, and three runs were made, the first with 150 pounds pressure of steam per square inch. The speed was 26 miles an hour and the maximum lift 2,750 pounds. The second run was made with 240 pounds of steam. The speed recorder on this occasion failed to work, but it is probable that the speed was 35 miles an hour. The maximum lift was 4,700 pounds. Then everything was made ready for a final test with practically the full power of the engines. Careful observers were stationed on each side of the track, and I took two men with me on the machine, the duty of one being to observe the pressure gauges, and that of the other to observe and note the action of the wheels on the upper track. The machine was tied up to a dynamometer, the engines started at a boiler pressure of 310 pounds and with a screw-thrust of a little more than 2,100 pounds. Upon liberating the machine it darted forward with great rapidity while the screws rotated at a terrific rate. I turned on slightly more gas and the pressure almost instantly rose to 320 pounds to the square inch and blew off at the safety-valve at that pressure. After running a few hundred feet, the machine was completely lifted off the lower rails, and all four of the upper wheels were engaged on the upper or safety rail. After running a few hundred feet in this position, the speed of the machine greatly increased and the lift became so great that the rear axletrees holding the machine down were doubled up and the wheels broken off. The machine then became liberated, the front end being held down only on one side. This swayed the machine to one side, brought it violently against the upper rails, and stopped it in the air, the lift breaking the rails and moving them outward about ten feet. Steam was, however, shut off before the machine stopped. The machine then fell to the earth, imbedding the wheels in the turf, showing that it had been stopped in the air, had come directly down, and had not moved after it touched the ground. Had this last experiment been made with a view to free flight, and had the upper rail been removed or the wheels taken off, the machine would certainly have mounted in the air and have travelled a long distance, if necessary. As it was, the lift certainly exceeded the full weight of the machine, the water, the fuel, and the men by 2,000 pounds, and was far beyond the registering limit of the dynagraphs, the pencil being drawn completely across the paper on the recording cylinders.

These experiments at Baldwyn's Park are the first that have ever been attempted with a machine running in a straight line. The prime object of these experiments has been to demonstrate whether it is possible or not for a large machine to be constructed sufficiently light, powerful, and efficient to actually lift into the air its own weight and the weight of one or more men. All other flying machines which have ever been built in the world have persistently stuck to the earth, and this is the first occasion in which a machine has ever been made to raise itself clear of the earth. It has been admitted by all scientists that as soon as a machine could be made with motors powerful enough to actually lift it in the air, aërial navigation would become practical. I have demonstrated that a good and reliable motor can be made with sufficient power for its weight to drive a flying machine, that a very heavy flying machine may be made to raise itself in the air with water, fuel, and three men on board ; and that it may lift, in addition to all this, 2,000 pounds. It now only remains to continue the experiments with a view of learning the art of manœuvring the machine ; and for this purpose it will be necessary for me to seek some large, open, and level plain, and to commence by making flights so near to the ground that any mistake in the steering cannot result in a serious mishap.

HIRAM S. MAXIM.